Agriculture, Ecosystems and Environment 312 (2021) 107342

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Changes in rainfall partitioning and its effect on soil water replenishment after the conversion of croplands into apple orchards on the Loess Plateau

Rui Zhang [a,b], Di Wang [a,b], Ziqi Yang [a], Katsutoshi Seki [d], Manmohanjit Singh [e], Li Wang [a,c,*]

[a] College of Natural Resources and Environment, Northwest A&F University, 712100, Yangling, China
[b] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, 712100, Northwest A&F University, Yangling, China
[c] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, 712100, Yangling, China
[d] Natural Science Laboratory, Toyo University, 1128606, Tokyo, Japan
[e] Regional Research Station, Punjab Agricultural University, Punjab, India

ARTICLE INFO

Keywords:
Throughfall
Stemflow
Rainfall amount
Replenishment efficiency

ABSTRACT

The partitioning of rainfall by plant canopies into throughfall (TF) and stemflow (SF) affects the process of rainfall infiltration into the soil as well as the ecological functions of soil water. A change in land use from croplands to orchards inevitably influences the preexisting rainfall partitioning and soil water replenishment processes. However, few studies have focused on the differences in TF and SF and their effects on soil water replenishment after converting croplands into apple orchards. Thus, the objectives of this study were to quantify the differences in TF and SF between maize (*Zea mays* L.) and apple trees (*Malus domestica*, cv. Fuji), clarify their influencing factors, and compare the efficiency of soil water replenishment by rainfall from June to September as well as the soil water content and storage in each hydrological year of the study. Under the same rainfall conditions, the rainfall was distributed differently due to the presence of the maize and apple tree canopies. The sum of the TF and SF in the maize field (129.1 mm and 167.6 mm) was lower than that in the apple orchard (250.4 mm and 354.2 mm) in 2017 and 2018, respectively; the TF amount in the apple orchard was on average 3.4 times that in the maize field, while the SF amount in the maize field was on average 12.9 times that in the apple orchard. The TF percentage ranged from 0 to 76.9 % and 0 to 97.9 % for the maize field and the apple orchard, respectively, while the SF percentage ranged from 0 to 37.5 % and 0 to 3.3 %. The soil water input sources for the maize field were TF and SF, while the input source for the apple orchard was mainly TF. TF and SF production increased linearly with rainfall in the apple orchard. The rainfall amount was identified as the variable with the greatest influence on rainfall partitioning among the rainfall factors considered. An increasing leaf area index resulted in decreasing relative TF but increasing relative SF for maize and decreasing relative TF and SF for apple trees. The mean efficiency of the replenishment of soil water by rainfall in the maize field (30.8 % and 37.4 % in 2017 and 2018, respectively) was slightly lower than that in the apple orchard (34.4 % and 41.0 %). This study provides insight into water cycle analyses aimed at understanding rainfall partitioning and the soil water environment within croplands converted into apple orchards on the Loess Plateau and in other, similar regions.

1. Introduction

Changes in global and regional climate have raised concerns about the potential impact of rainfall, especially in the arid and semiarid regions that make up one-third of the global land area (Wang et al., 2013; Li et al., 2020a). Arid and semiarid regions are also generally water-limited environments where rainfall is a major driver of ecohydrological processes in agricultural areas (Zheng et al., 2018). Rainfall reaches the canopy first, and a sizable amount of rainfall is intercepted by leaves and evaporates back into the atmosphere from the canopy surface (Zheng et al., 2019). The remaining amount is often called the net rainfall, and it becomes soil water after penetrating the plant canopy (Sadeghi et al., 2020). The net rainfall is the sum of throughfall (TF) and stemflow (SF); it is often the main or even sole source of soil water replenishment and a significant influence on plant growth and agricultural ecohydrological processes in water-limited areas (Jian et al.,

* Corresponding author at: State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, 712100, Yangling, China.
E-mail address: wangli5208@nwsuaf.edu.cn (L. Wang).

https://doi.org/10.1016/j.agee.2021.107342
Received 13 October 2020; Received in revised form 1 January 2021; Accepted 21 January 2021

2019). Throughfall includes droplets that never contact canopy surfaces and droplets that impact leaf surfaces or branches and fall to the soil surface below the canopy (Magliano et al., 2019a). Stemflow is defined as the small proportion of incident rainfall that runs along the stem or trunk to the soil surface (Cayuela et al., 2018). Throughfall is the "diffuse input" pathway through which rainfall supplements soil water; stemflow is the "direct input" pathway through which rainfall supplements soil water (Yuan et al., 2019). A literature review of dryland ecosystems with annual mean rainfall ranging from 154.0 mm to 900.0 mm reported that TF accounted for the largest component of the rainfall amount (69.8 %), while SF accounted for a much smaller component (6.2 %) (Magliano et al., 2019a). The partitioning and redistribution of rainfall that penetrates the plant canopy create marked variations in the spatial heterogeneity of subsurface water and can thus affect soil water recharge (Zheng et al., 2019). Throughfall and SF continuously replenish soil water, while plant transpiration and soil evaporation consume soil water; both of these processes together maintain the water cycle of the ecosystem (Wang and Wang, 2017). In addition, TF and SF carry atmospherically deposited and canopy-derived materials into the ground from the top of the canopy, thus integrating the biological, physical and chemical processes at the top and interior the canopy and connecting the aboveground and belowground parts of the ecosystem (Ponette-González et al., 2020). Stemflow concentrates the rainfall and nutrients in the vicinity of the base of the stem, and the water and nutrients can easily infiltrate the soil near the roots through soil animal passages and soil micropores (Zabret et al., 2018; Li et al., 2020b). Rainfall partitioning may indirectly influence the heterogeneity of nutrient availability by influencing the microbial environment and community and can thus affect the nutrient balance of the ecosystem (Aubrey, 2020). Rainfall partitioning influences the functioning of dryland agricultural ecosystems by affecting the two most limiting factors for plant growth, i.e., water and nutrient availability (Zhang et al., 2016).

Large-scale afforestation efforts have been carried out in many regions of the world (Sadeghi et al., 2016). In fact, forest plantations have become the preferred choice for many cropland revegetation activities (Sadeghi et al., 2016). The species grown in these plantations include pine (*Pinus eldarica*), arizona cypress (*Cupressus arizonica*), black locust (*Robinia pseudoacacia*), narrow-leafed ash (*Fraxinus rotundifolia*), and others (Michelozzi et al., 2008). After a large area of cropland is converted into forest, rainfall partitioning and the water cycle in the area experience substantial changes (Sadeghi et al., 2016; Geng et al., 2019). For example, Marin et al. (2000) reported that trees with a large canopy surface area and more complex canopy structure can decrease the TF and SF amount by increasing the losses from canopy interception. Literature reviews have shown that trees have higher evapotranspiration rates than crops because they have deeper root systems and taller, rougher canopies; thus, trees may not be conducive to soil water storage after rainfall replenishment (Benyon et al., 2006). Sadeghi et al. (2020) comprehensively analyzed 644 rainfall partitioning observations around the world and across climate zones and found that the most-sampled sites for TF and SF studies were forests used for fiber and wood and that few of these studies discussed economic forests. Less attention has been paid in the literature to comparative studies about cropland conversion to forests, especially to economic forests. In addition, the number of studies in drylands was lower than that in semihumid and tropical regions (Magliano et al., 2019a).

The difference in rainfall partitioning, i.e., the difference between the TF and SF amounts, among species can be large due to differences in meteorological variables (Cayuela et al., 2018). For example, Zabret et al. (2018) reported that the amount of rainfall was identified as the most influential variable for TF and SF and that lower wind speed was found to increase the TF of pine (*Pinus nigra* Arnold) and birch (*Betula pendula* Roth.). Zheng et al. (2019) indicated that rainfall events with greater intensity and higher rainfall amounts resulted in a more homogeneous redistribution of rainfall than weaker rainfall events. However, differences in plant traits are especially relevant when comparing different species in the same region because the different species experience similar climate factors. The morphology, canopy structure and branching architecture of different plants may also affect rainfall partitioning. Existing studies regarding the influence of plant traits on rainfall partitioning have generally focused on a single species. For example, Nazari et al. (2020) found that the TF of maize was significantly correlated with the leaf area index (LAI) and height of the canopy; Fang et al. (2015) indicated that canopy structure was a key factor influencing the spatial variation in TF for *Pinus tabulaeformis*.

Vegetation restoration activities such as the “Grain to Green” project, one of the larger restoration projects in China, have been implemented on the Loess Plateau (Geng et al., 2019). In this project, traditional agricultural crops, e.g., maize, were replaced with woody plants, e.g., apple trees. The Loess Plateau is an important food production base in Northwest China; the cropland area on the plateau was 1.6×10^4 km^2 by 1992, and maize is one of the most popular grain crops (Zheng et al., 2018). The area of apple orchards exceeded 7.3×10^3 km^2 in 2017, and apples had replaced field crops as the main income source for local farmers (Wang and Wang, 2017). The conversion of large areas of cropland into orchards resulted in significant changes in the hydrological environment (Geng et al., 2019). Recent studies have shown that revegetation on the Loess Plateau has already reached the limits of water resource sustainability. The effective use of soil water in the context of a large area of cropland being converted into orchards needs to be considered (Huang and Shao, 2019). Therefore, an improved understanding of the differences in rainfall partitioning caused by the transition from crops to economic forests and the replenishment of soil water by net rainfall are essential for establishing reasonable vegetation recovery plans that address water resources and plant management. The aims of this study were to (1) understand the differences in TF and SF between maize fields and apple orchards in a typical ecological restoration region on the Loess Plateau, (2) identify the key factors (meteorological characteristics and LAI) causing the differences in TF and SF, and (3) quantify the difference in soil water replenishment caused by the conversion of maize fields into apple orchards.

2. Materials and methods

2.1. Study sites

The experiment was conducted on the Changwu tableland on the southern Loess Plateau of China (1100.0–1300.0 m a.s.l.) (Fig. 1a, b). This region has a semihumid continental climate but often suffers from drought. The dark loessial soil is unsaturated and relatively deep (>100 m). The mean annual reference evapotranspiration was 1016.0 mm yr^{-1}. The mean annual rainfall was 519.6 mm (ranging from 209.7 mm to 1073.0 mm) in 2000−2018. Rainfall is the most important available water resource for ecosystems on the Loess Plateau because the ground water level is 50.0–80.0 m beneath the surface (Wang and Wang, 2017). Spring maize (*Zea mays* L.) is one of the major traditional crops and grows from mid-April until harvest in mid-September. The area of maize fields in the tableland was approximately 24.0 km^2 in 2019. Apple trees (*Malus domestica,* cv. Fuji) are used for ecological restoration and to increase the incomes of local farmers; most apple orchards on the Loess Plateau were planted in 2005 (Song et al., 2018). Apple trees bloom in late March and are harvested in early October. The area of apple orchards in the tableland was 167.7 km^2 in 2019.

In the present study, each experimental maize plot was 16.5 m long and 10.0 m wide. There were six replicates of the maize plot. Each experimental apple orchard plot was 14.0 m long and 10.0 m wide. There were eight replicates of the apple orchard plot (Fig. 1c). The morphological traits of the maize and apple trees and the soil physical property of the plots involved in throughfall and stemflow measurements was showed in Table 1.

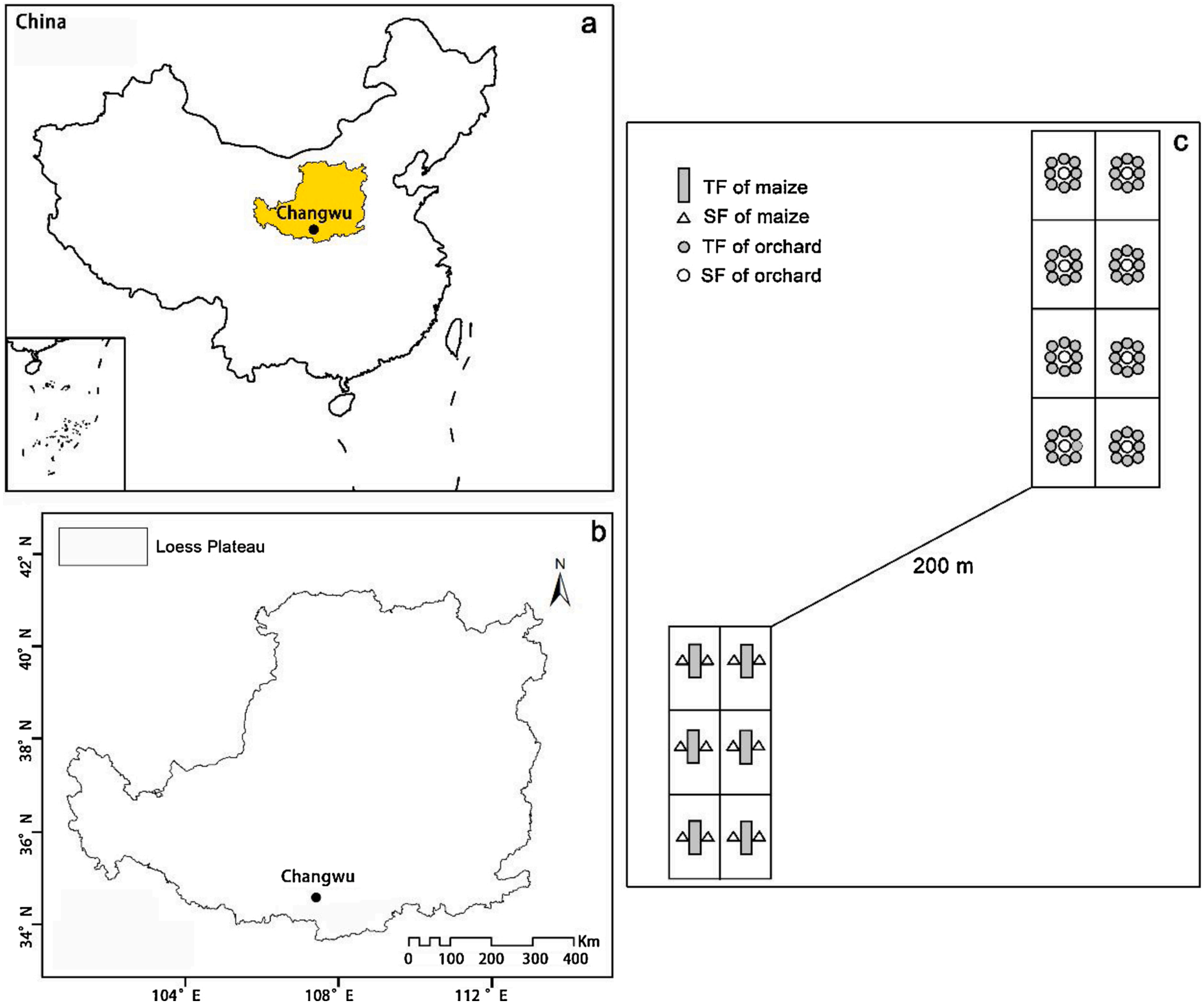

Fig. 1. Location and experiment design of the study site on the Loess Plateau.
Note: a is the map of China; b is the map of Loess Plateau; c is the map of experiment design; TF: throughfall; SF: stemflow.

Table 1
The morphological traits of maize and apple trees and soil physical property of plots involved in the throughfall and stemflow measurements.

Plant	Height (cm)	Basal diameter (cm)	Plant spacing (m)	Row spacing (m)	Soil layer (cm)	Bulk density (g cm^{-3})	Field capacity (cm^3 cm^{-3}, %)	Soil particle size (%) <0.01 (mm)	<0.01–0.001 (mm)	<0.001 (mm)
	310.2	4.9								
	319.6	5.3								
	321.1	5.3			0–10	1.3	30.0	23.8	62.9	13.3
	309.2	4.5			10–30	1.4				
	314.8	4.8								
Maize	316.9	5.1	0.7	0.6						
	308.4	4.5								
	311.0	4.5			30–50	1.4				
	315.4	4.7			50–70	1.3	28.1	26.4	63.5	10.11
	309.8	4.6			70–100	1.3				
	316.0	5.0								
	317.1	5.1								
	318.4	11.8								
	295.6	14.0			0–10	1.3	31.4	11.0	72.2	16.9
	340.1	13.4			10–30	1.3				
Apple trees	323.2	12.1	3.5	4.0						
	305.8	13.0								
	311.6	11.6			30–50	1.3				
	337.4	12.9			50–70	1.3	30.9	11.2	75.7	13.1
	352.2	13.6			70–100	1.3				

2.2. Meteorological variables

Meteorological variable data were collected during two hydrological years (from March 2017 to February 2018 and from March 2018 to February 2019). An automatic meteorological station was set up approximately 300.0 m away from the experimental fields to measure the air temperature (°C, AT), relative humidity (%, RH), wind speed (m s^{-1}, Ws), and hourly data on the amount of rainfall (mm). Wind speed data at a height of 10.0 m were converted to speeds for the standard height of 2.0 m using a logarithmic wind-speed profile and conversion factor (Allen et al., 1998). Rainfall events were separated by interval periods of at least 4.0 h. In the present study, the meteorological variables were further subdivided into rainfall factors, including the incident rainfall event amount (mm), the incident rainfall event duration (h), rainfall intensity (mm h^{-1}), and duration of the dry period from the previous to the present event (h, DryPeriod), and nonrainfall factors, including AT, RH and Ws.

2.3. Throughfall and stemflow measurements

The TF of the maize field was recorded using a horizontal iron trough (90.0 cm long and 50.0 cm wide). An iron trough was positioned between rows at the center of each plot. The TF of the apple orchard was recorded using horizontal homemade rain gauges. Each rain gauge was made from a metal can (inner diameter of 20.0 cm and height of 30.0 cm). Eight rain gauges were installed underneath each tree at a distance of 50.0 cm from the trunk along and perpendicular to the rows at or near the center of each plot. The rainwater weight data were obtained manually for both the troughs and the gauges.

Two maize plants and one apple tree in the center of each maize and apple plot, respectively, were used to obtain the SF. The SF was collected with breathable but dense sponges that were wrapped around the plant stems in a cone shape. The sponges were fitted around the entire circumference of the tree trunks at a height of 0.5 m and around the maize stalks at a height of 0.3 m. A container was connected by a pipe to the sponges, and the rainwater weight data in the container were obtained manually. The volumes of TF and SF were converted to depth based on the contribution area of the plant canopy.

The equivalent water depth of TF for maize (TF_m) and apple trees (TF_{12y}) was calculated as follows:

$$TF_m\ (TF_{12y}) = 10\sum_{i=1}^{n} TF_i \Big/ [S_m\ (S_{12y})\ *n] \tag{1}$$

The percentage of the incident rainfall amount that was TF for maize (TF_m%) and apple trees (TF_{12y} %) was calculated as follows:

$$TF_m\ (TF_{12y})\ \% = (TF_m\ (TF_{12y})/R)\ *100\ \% \tag{2}$$

where TF_m and TF_{12y} are in mm, TF_i is the average TF volume of each container for the ith plant (cm^3), R is the amount of incident rainfall, S_m is the iron trough bottom area (cm^2), S_{12y} is the rain gauge bottom area (cm^2), and n is the number of selected plants.

The equivalent water depth of SF for maize (SF_m) and apple trees (SF_{12y}) was calculated as follows:

$$SF_m\ (SF_{12y}) = 10\sum_{i=1}^{n} V_i \Big/ [n*s] \tag{3}$$

where SF_m and SF_{12y} are in mm, V_i is the SF volume (cm^3), S is the canopy area (cm^2), and n is the number of selected plants.

The percentage of the incident rainfall amount that was SF for maize (SF_m%) and apple trees (SF_{12y} %) was calculated as follows:

$$SF_m\ (SF_{12y})\ \% = (SF_m\ (SF_{12y})/R)\ *100\ \% \tag{4}$$

2.4. Leaf area index measurement

The LAI was measured once a week from May to September in 2017 and 2018. Canopy photographs were taken on cloudy and sunny days before sunrise or after sunset to ensure the accuracy of the measurements. A standard digital SLR camera equipped with an optical fisheye lens (Nikon D7200 + Nikon AF DX 10.5 mm f/2.8 G ED) was used to take 8–10 photographs of each field. The sample points were generally located at the center of each field or at 1/4 of the diagonal. The camera was kept horizontal and was used to shoot upward or downward based on the height of the plants. CAN_EYE software v6.47 (http://www6.paca.inra.fr/caneye) was used to process the photographs for the LAI determination. Eight clear photographs were selected for processing. The average LAI of the canopy photographs was obtained with CAN_EYE v5.1. This software provided the effective LAI as extracted from retrieved plant area index values.

2.5. Soil water monitoring

The soil water content (SWC) was measured with an ECH_2O EC-5 probe (Decagon Devices, Inc., Pullman, WA, USA). The EC-5 probes estimate the soil water content by indirectly measuring the dielectric constant of the soil (Cobos and Chambers, 2010). These sensors were installed in each field at five depths, 5, 20, 40, 60, and 100 cm in the central position. The measured depths of the sensors were considered to be 0–10, 10–30, 30–50, 50–70, and 70–100 cm. Data were collected every 1 h by data loggers. The soil water content was also measured with the weighting method after dried which were taken as the standard value of soil water content, then linear regression processes were conducted to establish the calibration function in multiple soil layers (Table 2). Therefore, the soil volumetric water content measured by the EC-5 was converted into the soil gravimetric water content. We defined 0−30 cm as the shallow layer and 30−100 cm as the deep layer of soil. The soil water storage (SWS) was calculated as:

$$SWS = SWC_i \times h_i \tag{5}$$

where SWS is in mm, i is the increase in the profile depth, and h_i is the profile depth (mm).

The amount of soil water provided by incident rainfall infiltration into the soil (ΔW) was calculated as:

$$\Delta W = \sum(\Delta W_R - \Delta W_0) \tag{6}$$

Table 2
The calibration equation of EC-5 for maize field and apple orchard.

Soil depth (cm)	Plot of maize	Plot of apple orchard
0–10	y = 1.6803x−10.487 R^2 = 0.5247	y = 1.3478x + 1.1784 R^2 = 0.6846
10–30	y = 2.13x−16.164 R^2 = 0.6936	y = 2.0332x−14.794 R^2 = 0.6152
30–50	y = 2.1092x−11.474 R^2 = 0.6148	y = 2.3294x−18.053 R^2 = 0.6282
50–70	y = 1.5243x−4.4958 R^2 = 0.5999	y = 1.779x−8.9838 R^2 = 0.5016
70–100	y = 1.9157x−13.476 R^2 = 0.8462	y = 1.4135x−6.5965 R^2 = 0.5285

Note: x is the gravimetric water content converted from the volumetric water content measured by EC-5, y is the corrected gravimetric water content.

where ΔW_R is the soil water stored at 0–10, 10–30, 30–50, 50–70 and 70–100 cm after rainfall (mm) and ΔW_0 is the soil water stored at 0–10, 10–30, 30–50, 50–70 and 70–100 cm before rainfall (mm).

The efficiency of the replenishment of soil water by rainfall (R_e) was calculated as (Tang et al., 2019):

$$R_e = \frac{\Delta W}{R} * 100\% \tag{7}$$

2.6. Data analysis

Linear regressions were employed to determine the relationships between the proportions of the partitioned net rainfall components and the incident rainfall amount. The *t*-test was performed to identify whether there is a statistical difference in TF% and SF% between the maize field and orchard. The correlations of TF and SF with rainfall factors (the amount of incident rainfall, duration of incident rainfall events, rainfall intensity, and DryPeriod) and nonrainfall factors (AT, RH and Ws) were analyzed using Pearson correlation analysis. All statistical analyses were performed with SPSS software (SPSS Inc., Chicago, USA), and the graphs were constructed using Origin 2018 (OriginLab Corporation, Northampton, MA, USA) for Windows.

3. Results

3.1. Rainfall characteristics and rainfall partitioning

A total of 186 rainfall events were observed during the study period (Table 3). From 1 March 2017 to 28 February 2018, 104 events were recorded delivering 567.2 mm, and from 1 March 2018 to 28 February 2019, 82 events were recorded delivering 564.0 mm. The gross rainfall in both hydrological years was higher than the multiyear mean value (519.6 mm). We defined five classes of gross rainfall, ≤ 5, 5–10, 10–15, 15–20 and > 20 mm, to determine the statistical significance of differences at different rainfall amounts. As shown in Table 3, small rainfall events (≤ 5 mm) occurred frequently (75.0 % and 68.3 % of the total rainfall events for the two hydrological years, respectively), but their contribution to the total rainfall was not the largest of the different classes (20.2 % and 12.0 % of the gross rainfall). The mean duration of $\leq$ 5 mm rainfall events was the shortest of all the classes. The $>$ 20 mm events made up 6.7 % and 8.5 % of the events in each hydrological year, respectively, but this class was the greatest contributor to the gross rainfall, accounting for 45.0 % and 54.2 %, respectively. The mean duration of $>$ 20 mm rainfall events was the longest. The average rainfall intensity for each rainfall event ranged between 0.4 ± 0.3 mm h^{-1} and 2.6 ± 1.8 mm h^{-1}. Because the rainfall events occurred intensively from June to September, the TF and SF measurement period was also concentrated in these months (Fig. 2).

Between March 1, 2017, and February 28, 2018, rainfall events for which TF and SF could be measured occurred 11 times in the maize field and 17 times in the apple orchard (Table 4). The cumulative TF and SF values were 76.6 mm and 52.5 mm, respectively, for the maize field and 246.8 mm and 3.6 mm for the apple orchard. The differences between the TF and SF in the apple orchard and the maize field were 170.2 mm and − 48.9 mm. Between March 1, 2018, and February 28, 2019, rainfall events for which TF and SF could be measured occurred 15 times in the maize field and 24 times in the apple orchard. The cumulative TF and SF values were 96.9 mm and 70.7 mm, respectively, for the maize field and 347.9 mm and 6.3 mm for the apple orchard. The differences between the TF and SF in the apple orchard and the maize field were 251.0 mm and − 64.4 mm. The frequency of rainfall events was inconsistent due to the different growth periods of the maize and the apple trees. TF and SF were measured in the maize field from early July to early September and in apple trees from early June to late September.

During the respective growth periods of the maize and apple trees, the TF% in incident rainfall events for the maize field ranged from 25.0 % to 63.2 %, with a mean value of 43.9 %, in 2017 and from 0 to 76.9 %, with a mean value of 38.8 %, in 2018; the SF% in incident rainfall events ranged from 5.6 % to 35.0 %, with a mean value of 22.6 %, in 2017 and from 0 to 37.5 %, with a mean value of 22.2 %, in 2018 (Fig. 3). The relationship between the TF%, SF% and the incident rainfall for maize was not clear. In the apple orchard, the TF% of the incident rainfall in 2017 and 2018 ranged from 25.0 to 96.3 % with a mean value of 70.8 % and from 0 to 97.9 % with a mean value of 67.8 %, and the SF% of the incident rainfall ranged from 0 to 1.9 % with a mean value of 0.8 % and from 0 to 3.3 % with a mean value of 1.2 %, respectively. Exponential relationships were determined between the incident rainfall and the TF %, SF% for the apple trees, and the asymptotic value was close to 90.0 % and 1.5 % respectively. The *t*-test identified that there were statistical differences in TF% and SF% between the orchard and maize field in 2017 and 2018 ($p < 0.01$).

The maize growth cycle is shorter than the apple growth cycle. Taking the maize growth cycle as a reference period (mid-April to mid-September), the mean TF% was higher (72.0 %, 62.5 %) in the apple orchard than in the maize field (43.9 %, 38.8 %) in 2017 and 2018, respectively (Fig. 4). The mean SF% in the apple orchard was lower (0.8 %, 1.2 %) than that in the maize field (22.6 %, 22.2 %) in 2017 and 2018, respectively. During this reference period, the apple orchard received 35.5 mm and 33.6 mm more net rainfall than the maize field in 2017 and 2018, respectively. Taking the apple tree growth cycle as a reference period (late March to late September), we assumed that the incident rainfall amount was equal to the TF of the maize field before maize planting and after maize harvesting. The mean TF% of the incident rainfall in the maize field was 63.7 % in 2017 and 61.7 % in 2018; these values were also lower than the mean TF% in the apple orchard (70.8 %, 67.8 %) in 2017 and 2018, respectively. The mean SF% of the incident rainfall in the maize field was 14.6 % in 2017 and 13.8 % in 2018; these values were higher than the mean SF% in the apple orchard (0.8 %, 1.2 %) in 2017 and 2018, respectively. During this reference period, the orchard received 12.1 mm and 14.0 mm more net rainfall

Table 3
Characteristics of rainfall from March 2017 to February 2019.

	March 2017 to February 2018						March 2018 to February 2019					
	Event number	Frequency (%)	Total amount (mm)	Percentage (%)	Mean duration ±SD (h)	Mean intensity ±SD (mm h^{-1})	Event number	Frequency (%)	Total amount (mm)	Percentage (%)	Mean duration ±SD (h)	Mean intensity ± SD (mm h^{-1})
≤5	78	75.0	114.8	20.2	3.5±2.4	0.5±0.6	56	68.3	68.0	12.1	3.1±2.6	0.4±0.3
5–10	10	9.6	72.4	12.8	9.1±3.4	1.0±0.5	12	14.6	86.2	15.3	7.2±1.5	1.1±0.4
10–15	6	5.8	76.8	13.5	10.8±7.4	1.9±1.6	4	4.9	53.0	9.4	12.0±3.5	1.2±0.6
15–20	3	2.9	48.4	8.5	10.3±5.7	2.1±1.5	3	3.4	51.2	9.0	22.0±15.5	1.4±1.4
>20	7	6.7	254.8	45.0	30.6±12.2	1.5±0.9	7	8.5	305.6	54.2	24.6±15.3	2.6±1.8
Total	104	100	567.2	100.0			82	100	564.0	100.0		

Note: SD: standard deviation for the events.

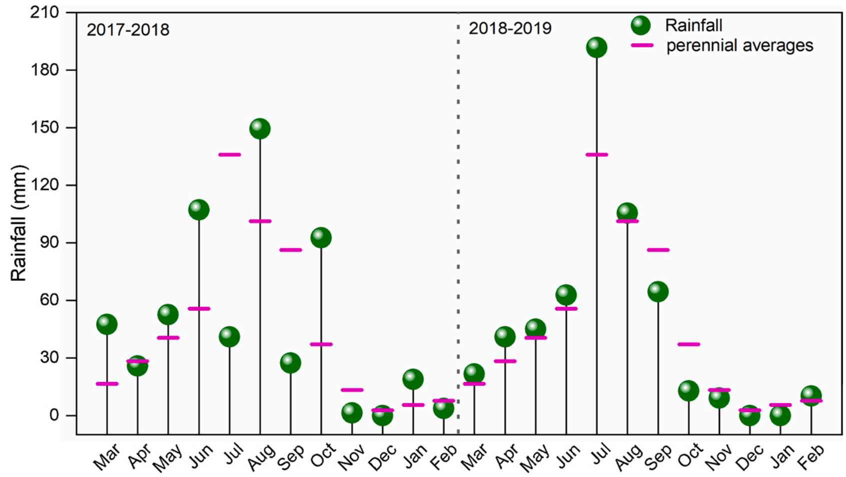

Fig. 2. The monthly distribution of rainfall in 2017-2018 and 2018-2019 as well as the perennial averages (2000-2018).

Table 4
Characteristics of the rainfall events involved in the throughfall and stemflow measurements.

Rainfall (mm)	Maize field						Apple orchard					
	2017			2018			2017			2018		
	Event number	Frequency (%)	Total amount (mm)	Event number	Frequency (%)	Total amount (mm)	Event number	Frequency (%)	Total amount (mm)	Event number	Frequency (%)	Total amount (mm)
≤5	4	36.3	9.8	7	46.6	9.4	5	29.4	13.6	10	41.7	14.4
5–10	0	0	0	2	13.3	14.6	1	5.9	5.4	3	12.5	21.8
10–15	3	27.3	36.4	1	6.7	10.2	5	29.4	62.2	2	8.3	24.8
15–20	1	9.1	15.4	1	6.7	17.6	2	11.8	30.8	2	8.3	36.4
>20	3	27.3	130.6	4	26.7	178.6	4	23.5	189.4	7	29.2	305.6
Total	11	100	192.2	15	100	230.4	17	100	301.4	24	100	403.0

than the maize field in 2017 and 2018, respectively.

3.2. Correlations of rainfall partitioning with meteorological variables and leaf area index

3.2.1. Rainfall partitioning in relation to meteorological variables

The Pearson and Partial correlation analyses revealed that TF of apple orchard was significantly correlated with the amount of rainfall ($p < 0.01$), while TF of maize field was significantly correlated with the amount of rainfall only in 2018 (Table 5). For SF, the rainfall amount was also the variable with the strongest Pearson correlation, and the second strongest correlation was also with the duration of rainfall events in the maize field and apple orchard. The Partial correlation analyses revealed that SF of apple orchard was correlated with the amount of rainfall ($p < 0.05$), while SF of maize field was significantly correlated with the amount of rainfall only in 2017.

In addition, RH, which is a nonrainfall factor, was correlated with TF and SF to a certain extent for both the maize field and apple orchard only in 2018 for Pearson correlation analyses. DryPeriod was correlated with SF to a certain extent for the apple orchard only in 2017 for Partial correlation analyses. The rainfall intensity, AH and Ws did not show correlations with the amount of TF or SF for either the maize field or the apple orchard.

3.2.2. Rainfall partitioning in relation to leaf area index

The relationships of LAI with TF and its percentage as well as with SF and its percentage are shown in Fig. 5. During the period from June to September, the LAI of the maize field initially increased and reached a maximum at the end of July, after which the LAI decreased gradually. The LAI was 1.8, 4.0 and 2.1 at three consecutive measurement times in 2017 and was 2.6, 3.7 and 2.2 in 2018. The variation trend in LAI in the apple orchard was basically the same as that in the maize field from May to September. The LAI of the apple orchard was 1.8, 3.0 and 2.2 at three consecutive measurement times in 2017 and 1.4, 1.9 and 0.3 in 2018. Because the apple trees experienced two frosts during the flowering period in April 2018, the overall LAI in 2018 was lower than that in 2017. A comparison of the LAI in the same period in 2017 showed that the LAI of the maize field was smaller than that of the apple orchard before mid-July; after that point, the LAI of the maize field became larger than that of the apple orchard. Starting at the beginning of July 2018, the LAI of maize was slightly larger than that of the apple trees.

When the ground was partly covered by the maize canopy (LAI $<$ 2.4), the main form of rainfall that reached the ground was TF. The LAI of maize gradually increased with growth, and the higher LAI meant that there was more leaf area to intercept the rainfall and convert it to SF. When the LAI reached a maximum, more than 50 % of the rainfall remained on the leaf surface and finally evaporated back into the atmosphere, except during heavy rainfall events. As the maize leaves gradually turned brown, the LAI decreased, the TF% and SF% increased compared to those in the previous period and the SF% reached its peak. For apple trees, the percentage and amount of TF decreased with the LAI increase from the beginning of May until they reached minimum values at the end of July. The SF also showed a downward trend with the increase in LAI, but LAI had little effect in terms of the SF% .

3.3. Infiltration of throughfall and stemflow to soil

During the same rainfall events, there were differences in the amount of soil water replenishment in the maize field and the orchard, but these differences were not significant ($p > 0.05$) (Table 6). From June to September in each hydrological year, the total ΔW of the maize field was 123.6 mm and 165.5 mm and the total ΔW of the apple orchard was

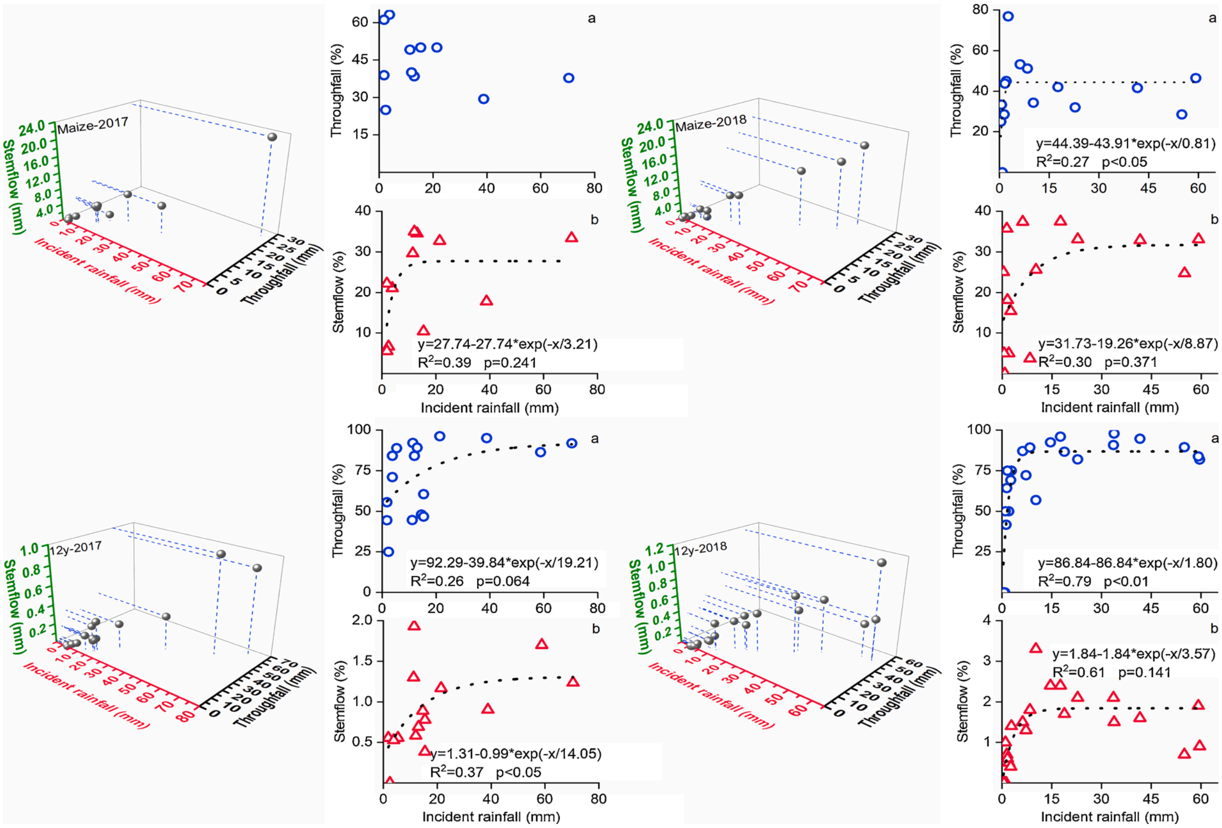

Fig. 3. The relationships of throughfall (y-axis) and stemflow (z-axis) and their percentages to the incident rainfall amount (x-axis).
Note: 12y: 12-year-old apple orchard.

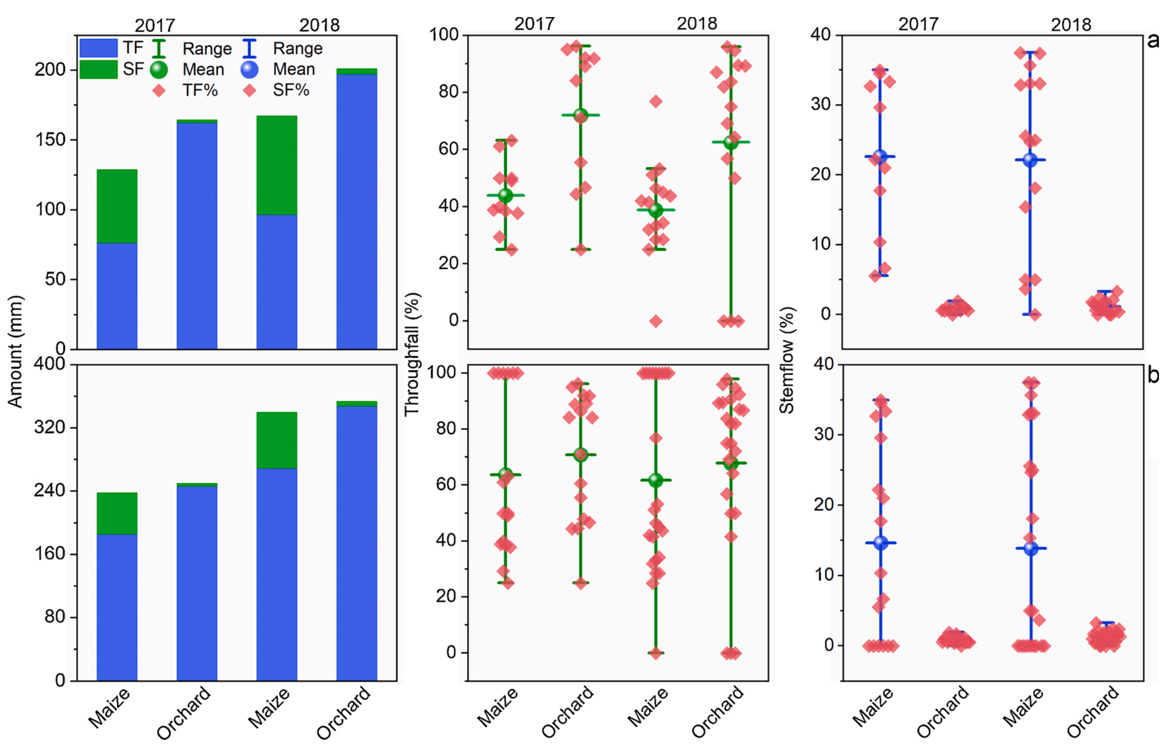

Fig. 4. The distribution of throughfall and stemflow and their percentages for the maize field and the apple orchard during the same growth periods.
Note: a: The maize growth cycle as the reference period (mid-April to mid-September); b: The apple tree growth cycle as the reference period (late March to late September). Orchard: 12-year-old apple orchard.

Table 5
Pearson and Partial correlations between throughfall, stemflow and meteorological variables.

		Period	Incident rainfall event amount (mm)	Incident rainfall event duration (h)	Intensity (mm h^{-1})	DryPeriod (h)	AT (°C)	RH (%)	Ws (mm s^{-1})
Pearson-Throughfall (mm)	Maize	2017	0.958**	0.687**	0.479	−0.536	−0.096	0.412	0.231
		2018	0.992**	0.950**	0.121	−0.036	−0.269	0.566*	0.020
	Orchard	2017	0.987**	0.813**	0.141	−0.368	−0.215	0.390	0.070
		2018	0.992**	0.834**	0.217	0.078	0.003	0.541**	−0.011
Partial-Throughfall (mm)	Maize	2017	0.626	0.234	0.538	−0.187	0.126	0.406	0.496
		2018	0.948**	0.813	0.449	0.212	−0.297	−0.104	0.025
	Orchard	2017	0.956**	0.125	0.073	−0.346	0.484	0.526	−0.298
		2018	0.962**	−0.185	−0.069	0.220	−0.045	−0.101	−0.039
Pearson-Stemflow (mm)	Maize	2017	0.919**	0.609*	0.411	−0.568	0.000	0.515	0.050
		2018	0.991**	0.909**	0.212	−0.046	−0.184	0.573*	0.014
	Orchard	2017	0.677**	0.604**	0.001	0.156	−0.203	0.386	−0.090
		2018	0.880**	0.758**	0.309	0.003	0.019	0.574**	−0.075
Partial-Stemflow (mm)	Maize	2017	0.848*	−0.566	−0.499	−0.180	0.591	0.706	0.050
		2018	0.920	0.432	0.538	−0.352	0.388	−0.090	−0.035
	Orchard	2017	0.579*	−0.127	− 0.084	0.702**	−0.088	0.259	−0.332
		2018	0.486*	0.187	0.361	−0.151	0.029	0.087	−0.089

Note: *, **significance at p < 0.05, <0.01, respectively. Orchard: apple orchard. AT: air temperature, RH: relative humidity, Ws: wind speed.

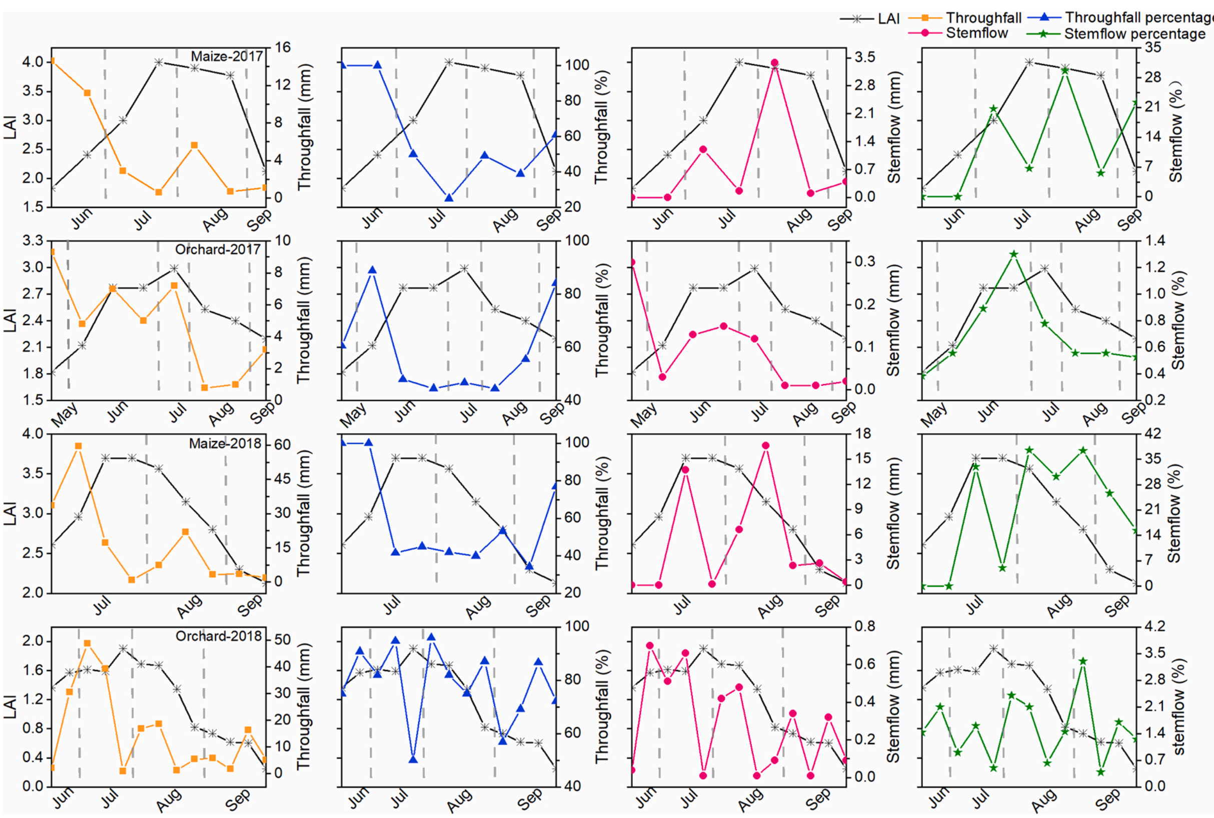

Fig. 5. Variations in throughfall, stemflow and their percentages against LAI.
Note: LAI: leaf area index, Orchard: 12-year-old apple orchard.

127.6 mm and 176.2 mm in 2017 and 2018, respectively. Among the eleven rainfall events (3.8 mm–74.2 mm) in 2017, the ΔW of the maize field was higher than that of the apple orchard in four events. Among the thirteen rainfall events (6.2 mm–59.6 mm) in 2018, the ΔW of the maize field was higher than that of the apple orchard in seven events. The rainfall events in which the ΔW of the maize field was significantly higher (> 7.0 mm) than that of the apple orchard were > 40.0 mm events. The rainfall events in which the ΔW of the orchard was significantly higher (> 5.0 mm) than that of the maize field were 30.0–40.0 mm and > 55.0 mm events.

Among the eleven rainfall events (3.8 mm–74.2 mm) in 2017, the R_e of the maize field was higher than that of the apple orchard in four events. Among the thirteen rainfall events (6.2 mm–59.6 mm) in 2018, the R_e of the maize field was higher than that of the apple orchard in seven events. Of the eleven rainfall events in which the R_e of the maize field was higher than that of the apple orchard, there were five events in which the event class was > 40.0 mm; of the thirteen rainfall events in which the R_e of the apple orchard was higher than that of the maize field,

Table 6
The amount and efficiency of rainfall replenishment of soil water for the maize field and apple orchard.

	Date	$\Delta W$of maize (mm)	$\Delta W$of orchard (mm)	Difference in ΔW (mm)	R_e of maize (%)	R_e of orchard (%)	Mean Re of maize (%)	Mean Re of orchard (%)
2017	Jun 5	41.1	37.2	−3.9	55.4	50.1	30.8	34.4
	Jun 11	0.6	1.1	0.5	11.1	19.7		
	Jun 22	4.7	4.9	0.2	42.3	44.1		
	Jul 17	1.2	5.3	4.1	7.9	34.4		
	Jul 29	1.0	2.5	1.5	9.0	22.2		
	Aug 8	1.2	2.9	1.7	9.3	22.1		
	Aug 19	5.5	7.3	1.8	25.8	34.0		
	Aug 23	41.5	37.9	−8.6	58.9	53.8		
	Aug 31	19.2	24.8	5.6	45.9	63.9		
	Sep 6	7.3	3.6	−3.7	60.8	29.9		
	Sep 17	0.3	0.1	−0.2	9.0	3.7		
Total		123.6	127.6	4.0				
2018	Jun 26	7.4	15.5	8.1	21.9	46.1	37.4	41.0
	Jul 5	35.0	32.5	−2.5	58.7	54.6		
	Jul 9	18.9	18.3	−0.6	55.8	54.1		
	Jul 11	17.8	27.4	9.6	30.1	46.2		
	Jul 16	16.7	9.7	−7.0	40.2	23.4		
	Aug 12	14.2	14.1	−0.1	62.5	62.2		
	Aug 23	36.3	36.2	−0.1	66.1	65.8		
	Aug 26	0.1	0.5	0.4	0.6	8.1		
	Sep 3	4.9	2.9	−2.0	48.4	28.4		
	Sep 5	3.0	2.9	−0.1	35.9	35.0		
	Sep 15	3.1	5.2	2.1	21.1	35.6		
	Sep 19	8.0	9.3	0.3	42.6	49.6		
	Sep 26	0.1	1.7	1.6	2.0	23.8		
Total		165.5	176.2	10.7				

Note: ΔW : the amount of incident rainfall replenishment of soil water, Difference in ΔW : ΔW of orchard minus ΔW of maize, orchard: apple orchard.

there were four events in the 10−15 mm class and four events in the > 20 mm class. The mean R_e of the maize field was 30.8 % and 37.4 %, and the mean R_e of the orchard was 34.4 % and 41.0 % in 2017 and 2018, respectively. In terms of the overall R_e, that of the maize field was slightly lower than that of the apple orchard from June to September.

3.4. Correlation analysis of soil water replenishment efficiency

We selected the meteorological factors that were significantly related to TF and SF as shown in Table 5 ($p < 0.05$) and two factors that were related to soil water to analyze whether these factors were correlated with R_e (Table 7). For the maize field, there was no correlation between R_e and the SWC before rainfall or the SWS before rainfall in any year. The amount of incident rainfall was significantly correlated with R_e at the $p = 0.01$ level and at the $p = 0.05$ level in 2017 and 2018, respectively. The duration of incident rainfall events was significantly correlated with R_e at the $p = 0.05$ level in 2017, but this relationship was not found in 2018. For the apple orchard, R_e was negatively correlated with SWC before rainfall and SWS before rainfall only in 2018 ($p < 0.01$). R_e was significantly correlated with the amount of incident rainfall at the $p = 0.01$ level in 2017 and at the $p = 0.05$ level in 2018. The correlation between the duration of incident rainfall events and R_e was significantly positive only in 2017 ($p < 0.01$). Based on the magnitudes of the correlation coefficients, we determined that the amount of incident rainfall was related to the R_e in both the maize field and the orchard, but the correlation coefficients were different; the correlation coefficient of the maize field was higher than that of the apple orchard.

Table 7
Pearson correlation analysis of replenishment efficiency in the maize field and the apple orchard.

	2017		2018	
	R_e of maize	R_e of orchard	R_e of maize	R_e of orchard
SWC before Rainfall (%)	0.133	−0.109	−0.163	−0.580**
SWS before Rainfall (mm)	−0.029	−0.167	−0.196	−0.584**
Incident event amount (mm)	0.760**	0.737**	0.589*	0.576*
Incident event duration (h)	0.686*	0.768**	0.499	0.457

Note: *, **significance at $p < 0.05$, < 0.01, respectively. R_e: The efficiency of the replenishment of soil water by rainfall, SWC: soil water content, SWS: soil water storage, orchard: apple orchard.

3.5. Soil water variation in the maize field and orchard

The temporal variations in soil water at different depths in the maize field and apple orchard as well as in the rainfall distribution during the experiment are shown in Fig. 6. The mean SWC values of the maize field in the 0−10, 10−30, 30−50, 50−70 and 70−100 cm soil layers were 16.5 %, 17.8 %, 17.7 %, 17.2 and 16.5 % and 17.7 %, 18.4 %, 16.9 %, 16.6 % and 17.0 % in 2017–2018 and 2018–2019, respectively. The mean SWC values of the orchard for the same soil layers were 17.0 %, 17.8 %, 17.3 %, 17.4 % and 16.2 % in 2017–2018 and 18.2 %, 18.8 %, 18.0 %, 18.0 % and 18.3 % in 2018−2019. The SWC of the whole soil profile (0−100 cm) in the maize field changed only slightly from late March to late June, while the SWC in the orchard showed an obvious decreasing trend. When intense rainfall events arrived, the SWC was replenished by the rainfall, resulting in an obvious increase in SWC within 100.0 cm depth in the different fields. The results also showed that the SWC was relatively stable in autumn and winter, which was not a frequent rainfall replenishment period, and the SWC showed gradual downward trends in both the maize field and the orchard in autumn and winter.

The SWS in the 0−100 cm soil layer in the maize field and the orchard during the experiment are shown in Fig. 7. The initial SWS in the maize field was slightly lower than that in the orchard before experiment period, but the difference between the two fields was not significant ($p > 0.05$). In both the maize field and the orchard, the SWS in the

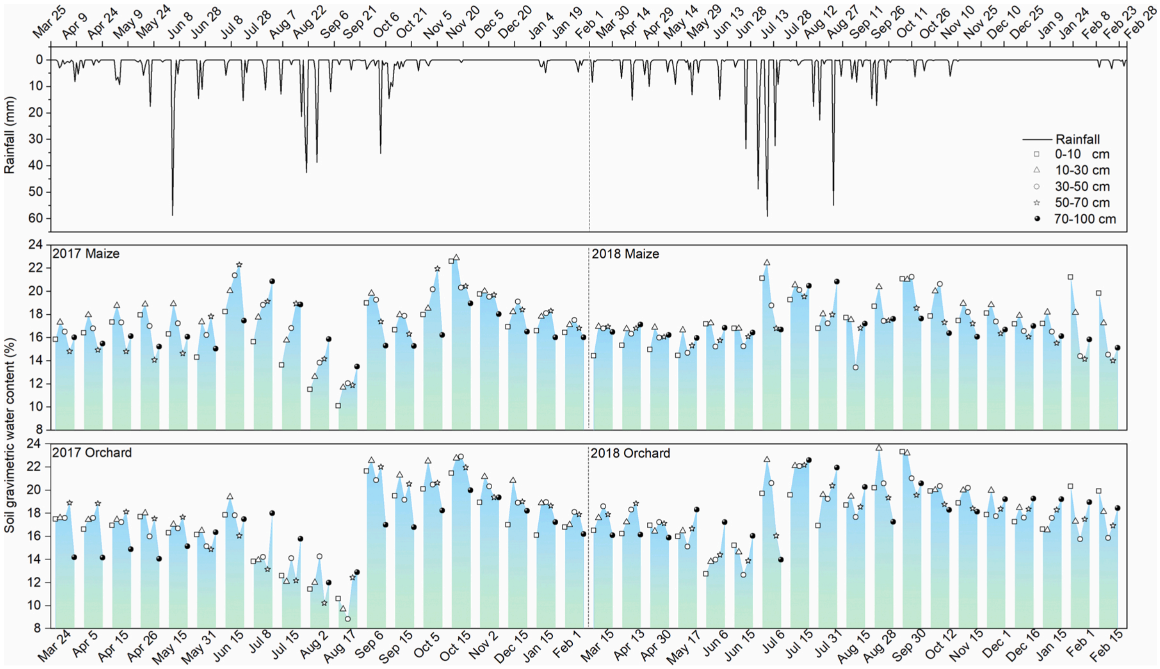

Fig. 6. Soil gravimetric water content in the maize field and apple orchard from March 2017 to February 2019.
Note: Orchard: 12-year-old apple orchard.

Fig. 7. Soil water storage (0-100 cm) in the maize field and apple orchard from March 2017 to February 2019.
Note: Orchard: 12-year-old apple orchard.

whole soil profile decreased from late March until late May. From June to September in 2017, the SWS of the maize field was higher than that of the apple orchard, and from July to September in 2018, the SWS of the maize field was lower than that of the apple orchard. At the end of plant growth, the SWS in the maize field at 0−100 cm soil depth was slightly lower than that in the orchard. The SWS in the two areas showed relatively stable downward trends after October.

4. Discussion

4.1. Differences in rainfall partitioning between the maize field and the apple orchard

4.1.1. The effect of meteorological variables on rainfall partitioning

In this study, we discuss the amount of rainfall that falls through the canopy and reaches the soil. The TF of maize ranges from 0 % to 90.0 % in the published literature (Sun et al., 2017), and the TF% (0 %–76.9 %) that we determined were consistent with those in previous studies. The SF of maize ranged from 0 % to 37.5 %, which was also consistent with those in other studies (0 %–60.0 %) (Zheng et al., 2018, 2019). Literature reviews on woody plants report that TF represents the largest component of ground rainfall input (typically 70.0 % of gross rainfall), while SF usually represents 5 % of gross rainfall (Sadeghi et al., 2016). Our TF (0 %–97.9 %) and SF (0 %–3.3 %) results for the apple orchard were within the range reported by previous studies on woody plants (Marin et al., 2000; Xiao et al., 2000). Although SF accounts for a small proportion of rainfall on apple trees, it still influences nutrient cycling and soil biogeochemical characteristics (Cayuela et al., 2018). Studies have shown that gross rainfall and its intensity affect rainfall partitioning in high evaporation potential regions, such as the Loess Plateau, where rainfall events of less than 5.0 mm are mostly considered to be ineffective or unproductive rainfall (Zheng et al., 2018). In this study, we also found that the amount of incident rainfall was recognized as the most influential variable ($p < 0.01$) on rainfall partitioning among rainfall factors; this finding has been previously reported by other authors as well (Jian et al., 2018; Yuan et al., 2019). The small rainfall events ($\leq$ 5 mm) produced little or no TF or SF for the maize and the apple trees. Zhang et al. (2020) reported similar results in a study of shrubs and found that small rainfall events may need an antecedent rainfall event in order to reach the canopy water storage capacity of the plants and initiate TF and SF. However, we did not find that rainfall intensity was correlated with TF or SF. This finding is complicated by the fact that large events tend to last longer than small events and thus tend to have lower average intensities (Staelens et al., 2008). The relationships between TF and SF and rainfall intensity can be meaningfully determined after an analysis that controls for the event duration (Keim, 2004).

Among the three basic nonrainfall factors, AT, RH, and Ws, there were no significant Partial correlations with rainfall partitioning. Zabret et al. (2018) reported that TF generally increased with decreasing AT for *Pinus nigra* Arnold and *Betula pendula* Roth. in a subalpine climate in Slovenia but that AT did not affect the SF. The climate in our study area is different from that in the area that Zabret et al. (2018) studied, which may be the reason for the inconsistent results for correlations between TF and AT. Study had shown that higher humidity was conducive to TF and SF of trees (Levia and Germer, 2015), but the average RH of rainfall events measured TF and SF was relatively lower (86.4 % and 85.6 %) in our study area. No significant effects of Ws on TF and SF were found for our studied plants. In contrast, higher SF generation with increasing Ws and decreasing TF with increasing Ws at Ws greater than 1.7 m s^{-1} were observed in two open-grown trees (Xiao et al., 2000). However, the Ws was rarely greater than 1.7 m s^{-1} in our study area.

4.1.2. The effect of plant traits on rainfall partitioning

Rainfall has a primary effect on TF and SF. Marin et al. (2000) indicated that rainfall partitioning depends on the rainfall amount and other rainfall characteristics; when rainfall events are similar, rainfall partitioning is more dependent on plant traits. We found that maize generated more SF than apple trees, and the differences in the proportion of SF between the maize field and the apple orchard were as high as 35.0 %. Given that the plants experienced the same meteorological conditions, the difference in rainfall partitioning between the two species may thus be attributed to the differences in their LAI. The present study also confirmed that the plant LAI affected the spatial distribution of the net rainfall that reached the soil surface (Bialkowski and Buttle, 2015). An investigation into various plants indicated that LAI changed significantly among different phenophases and influenced TF and SF (Marin et al., 2000). Zheng et al. (2018) reported that the LAI of maize gradually increased with leaf budding and that leaf expansion had a significant effect on SF collection and weakened TF production; these findings can be explained by the fact that erect leaves favor SF and interception (Sun et al., 2017). In apple trees, before the LAI reaches its maximum, only a small area of the ground is shaded by the canopy. The average LAI of the apple trees was small compared to that of maize, with a weaker capability for SF production and canopy interception loss; thus, the TF% of the apple trees was larger than that of the maize (Zheng et al., 2018). However, the SF of maize did not reach its highest value when the LAI was close to the maximum value. This likely occurred because more rainwater was stored on the dense leaf surface and finally evaporated back into the atmosphere, especially during small rainfall events (Liu et al., 2015). After the peak LAI period, the leaves were still collecting and transmitting rainwater, and the relative reduction in LAI led to a decrease in the efficient leaf interception area; as a consequence, the maximum SF% occurred during this period, and the relative TF showed an increasing tendency (Liu et al., 2015). When the LAI of the apple orchard increased to a maximum, one side of the trees tended to collect rainwater; this prevented the branches and trunks on the other side from becoming wet and conducting water along the trunk, so there was little SF (Staelens et al., 2008). The TF% for both the maize field and the apple orchard increased after the LAI decreased gradually; this may be due to the leaves increasingly bending downward due to plant senescence (Sun et al., 2017).

The TF and SF for the maize orchard and the apple orchard were different, probably also due to plant morphology (Marin et al., 2000). In our study, the apple trees were open-center systems with elliptical canopies, while the maize leaves were flat, which was more conducive to collecting rainwater and allowing it to flow along the stem (Liu et al., 2015). The insertion angle of maize leaves and apple branches affects rainfall partitioning, especially in terms of SF (Magliano et al., 2019b). Zheng et al. (2019) indicated that a large quantity of rainfall on maize leaves tended to become SF due to the influence of the high insertion angle of maize leaves on water transfer. Magliano et al. (2019b) supported the finding that a higher stem insertion angle resulted in more SF and suggested that stem angle could be used as a proxy for stemflow generation not only in *Larrea* spp. but also in other morphologically similar plant. The angles between the apple tree branches and the trunk were more vertically oriented than those in maize due to manual tree shaping. The apple tree's dense leaf crown coverage provided a large area for water interception, and the shape was not conducive to SF collection along the trunk, so TF was generated by crown drip or direct drip (Xiao et al., 2000). Our research found that SF in apple trees did not increase substantially even when heavy rainfall events occurred, and the heavy rainfall events increased the probability of branch drip by overloading the preferential flow paths on trunks; therefore, more potential SF had to become TF (Staelens et al., 2008).

4.1.3. Relationships of throughfall percentage and stemflow percentage to rainfall

Our results showing that the SF% of maize and the TF% and SF% of apple trees showed increasing tendencies with increasing incident rainfall amounts were in accordance with the results found by other researchers for maize (Zheng et al., 2018) and four forests (Marin et al., 2000). Our result did not show a clear exponential relationship between rainfall and SF% for maize; this result is inconsistent with the partial findings of Zheng et al. (2019), whose results show that the fitting results were better in the tasseling and ripening stages of maize. Our result was in accordance with the findings of Nazari et al. (2020). This may reflect the necessity of fitting the relationships between rainfall and SF in different growth stages. The exponential relationships between rainfall and the TF% and SF% of apple trees were also consistent with those for some other species, e.g., Xiao et al. (2000) found similar relationships between rainfall and the TF% of pear (*Pyrus calleryana*) and cork oak (*Quercus suber*), and Staelens et al. (2008) reported a similar relationship for *Fagus sylvatica* L.

4.2. Impacts of rainfall partitioning on soil water

The plant canopy affects the distribution and amount of rainfall that reaches the soil surface, thus affecting the amount of water available for plant use as well as the regional water cycle (Han et al., 2018). Under similar groundwater depth and topography conditions, soil water replenishment is strongly affected by plant traits as well as by rainfall (Molina et al., 2019). The temporal and spatial variations in soil water are the comprehensive results of soil water inputs and consumption (Yang et al., 2018). Due to the low frequency of rainfall events and the germination of plants, SWC showed slight changes in spring, and there were no obvious differences in soil water between the maize field and the orchard. Meteorological data from many consecutive years indicated that approximately 66.5 % of the annual rainfall fell from June to September on the Loess Plateau (Jia et al., 2019). Rainfall events close to or above 10.0 mm in which the soil water was obviously recharged mostly occurred during this period. This result is basically consistent with typical findings of rainfall partitioning studies showing that approximately 8.0 mm is the minimum rainfall required to saturate the canopy cover; at levels above 8.0 mm, the rainfall will fall to the ground (Molina and Campo, 2012). The results of soil water monitoring in the two fields showed that the replenishment effect of rainfall on soil water can reach 100.0 cm depth, and the changes in SWC that followed rainfall events indicated that the SWC was greatly affected by rainfall under the two plant species; as Bialkowski and Buttle (2015) showed that TF and SF significantly contributed to soil water recharge. Stemflow effectively supplied water to the soil profile of the maize field during large rainfall events ($>$ 40 mm). The presence of aerial roots helped water move to the deep soil layer along the large pores around the roots, and the soil water in the maize field was recharged more than that in the orchard (Zheng et al., 2019).

The replenishment of soil water by rainfall varies among different plant species, i.e. different land use. The land use changed affect the infiltration of rainfall and soil water dynamics by affecting the ground cover by the canopy (Wang et al., 2013). Molina et al. (2019) indicated that the mean SWC under different trees was closely related to the net rainfall, which was affected by the canopy cover. The LAI of the maize field was higher than that of the apple orchard from mid-July to early September, and the higher LAI reduced the net rainfall that reached the ground. After land use changed, the soil physical properties resulting from the interaction between agroecosystem and environment makes the water infiltration changing (Liao et al., 2001). The maize roots were densely distributed within the 0−30 cm soil layer, the soil compaction in the maize field was relatively higher than that in the apple orchard in the shallow soil (0−30 cm) (Zheng et al., 2019). Wang et al. (2013) reported that the ratio of water infiltration to rainfall in different land use was different, the infiltration percentage of *Robinia pseudoacacia* was higher than that of maize because of greater soil viscosity in cropland. These conditions were not conducive to the absorption of rainwater (Zheng et al., 2019). The different ΔW between the maize field and the apple orchard during large rainfall events may also have been affected by fertilizers, although we did not determine the chemical properties of the soil. However, as reported by Molina et al. (2019), soil layers with high nutrient levels may be indicative of strong organic decomposition and mineralization processes, which likely affect water infiltration. Fertilizer was applied to the apple trees in March and to the maize in late April. The fertilization time for the maize field was closer to the period of frequent rainfall than that for the orchard. Fertilizer was applied once enough to the maize field during our experiments. The time and amount of fertilization may have had a higher impact on rainwater infiltration in the maize field than in the orchard (Yang et al., 2018), thus affecting the R_e of the maize field.

The frequent replenishment of soil water as well as soil surface evaporation and root absorption processes increased the variability of SWS, resulting in the highest change occurring in the 0−100 cm soil layer from June to September in the two fields (Wang and Wang, 2017). By the beginning of October, the maize and apples had been harvested, the frequency of rainfall events decreased sharply, and the soil water in the maize field and the orchard tended to remain stable. However, the relative size of the SWS of the two fields is different in the two hydrological years. The result was consistent with some studies that have indicated that the spatial variability of SWC will vary with land use changes (Wang et al., 2013; Zheng et al., 2019). In 2018, apple trees suffered from frost and reduced production. The use of soil water was reduced, which showed an inconsistency with 2017, that is, the SWS was higher than that of cropland.

4.3. Implications

Rainfall is the sole source of soil water in the rain-fed region of the Loess Plateau. Rainfall partitioning affects the amount and the spatial distribution of the effective rainwater that enters the soil, strongly controlling plant survival and influencing the water cycle. After the conversion of the maize field into an apple orchard, the redistribution pattern of rainfall penetrating the canopy changed significantly. The TF of the apple orchard was on average 3.4 times that of the maize field, while the SF of the maize field was on average 12.9 times that of the apple orchard. The TF and SF amounts of the maize field and apple orchards were higher in 2018 than in 2017, but the relative sizes of the SWS in the maize field and apple orchard were inconsistent in the two hydrological years. It may be helpful to clarify that the impact of rainfall redistribution on soil water is weaker than the impact of plant. We found that the R_e of the orchard was slightly higher than that of the maize field in each year, indicating that rainfall can support the growth of apple trees in this region and that, at least until the trees are 12 years old, the soil water conditions in the 0−100 cm layer will not deteriorate. Our results also demonstrate that this conversion does not lead to the deterioration of soil water conditions during the young stand stage of apple trees. Because apple trees greatly increase the income of farmers, the conversion from croplands to orchards is increasing under local government policies. However, apple trees are perennial plants that have deep roots and consume large amounts of water, and the Loess Plateau sometimes suffers from drought. To increase the replenishment of soil water by TF and SF, from the perspective of sustainable ecological and hydrological development, appropriate density adjustments and canopy management practices should be implemented in apple orchards; studies have shown that reducing planting density does not affect apple yields and improves apple quality (Zhang et al., 2009; Arampatzis et al., 2018). The possible limitation of the presented study was not to quantify the amount of TF and SF on the soil water replenishment separately. The future research focus is to determine the respective impacts of TF and SF on the soil water replenishment, and the key effects of TF and SF changes on soil water after cropland converted to orchard.

5. Conclusions

In the present study, we measured the TF and SF of a traditional crop, maize, as well as those of apple trees planted to convert a cropland into an orchard. By comparing the results for the two species, the differences in rainfall partitioning and their effects on soil water were clarified for an agroecosystem on the Loess Plateau. The apple orchard obtained more TF than the maize field, while stemflow accounted for a higher percentage of the incident rainfall amount in maize than in apple trees. The TF and SF percentages of the apple orchard showed exponential relationships in their responses to the rainfall amount. The incident rainfall amount was recognized as the most influential variable on rainfall partitioning among the rainfall factors considered. Under the same rainfall conditions, LAI affected rainfall partitioning and soil water replenishment. After the conversion of croplands into orchards, the source of soil water replenishment was also significantly different. The sources of soil water replenishment in the maize field were TF and SF and that in the apple orchard was TF. The mean R_e of the maize field was slightly lower than that of the apple orchard; that is, the proportion of rainfall that became soil water in the apple orchard was greater than that in the maize field. This result suggests that soil water resources will also change to a certain extent after conversion. These findings regarding rainfall partitioning for maize and apple trees and soil water replenishment by TF and SF provide a reference basis for the conversion of croplands into orchards.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgments

We thank the Chinese Ecosystem Research Network, Changwu Agroecological Experimental Station for providing experimental support. This work was supported by National Natural Science Foundation of China (41771545 and 41977012), Strategic Priority Research Program of Chinese Academy of Sciences (XDB40000000), and the State Key

Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, CAS (ref no. SKLLQG1718).

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